THE NSLS SOURCE DEVELOPMENT LABORATORY: A WORK IN PROGRESS

Erik D. Johnson
SDL Project Manager

The objective of the Source Development Laboratory (SDL) is to facilitate the coordinated development of sources and experiments to produce and utilize coherent sub-picosecond synchrotron radiation. It is part of the fabric of accelerator technology development at Brookhaven, and of amplifier based free electron laser (FEL) development internationally. The NSLS provides much of the intellectual drive for this community, as well as support for the SDL experiments. Fundamental theoretical and experimental contributions have been made to the field by NSLS physicists. Without this groundwork, stretching back over more than a decade, the SDL program, and indeed those of other laboratories, would not exist as we now know them. Of particular note are the development of high current - high brightness electron beam technologies at the Accelerator Test Facility, and the theoretical framework for high gain FELs and subharmonically seeded single-pass FELs. These are the BNL "home-grown" cornerstones of the ultra-violet FEL experiments to be undertaken at the SDL.

Figure 1: Photograph of the SDL assembly in progress, November 1996.

For the NSLS, the SDL represents a new opportunity for its user community. The ultra-violet FEL (UV-FEL) will operate to wavelengths below 100 nm, and will produce radiation with substantially shorter pulses than are available from the VUV Ring (as brief as *5 fs*!) with peak power ranging from hundreds of Megawatts to as high as 100 Gigawatts for the shortest pulses. The bandwidth of the FEL can to some extent be controlled within the constraints of the Fourier transform limited nature of the source (trading pulse length for bandwidth). In terms of peak power, this source will open territory completely uncharted by existing tunable sources. From the standpoint of average power however, the picture is not nearly as exciting. The repetition rate available from the SDL linac will be at most 10 Hz, so for many experiments, the SDL will be a site for "proof-of-principle" studies. None the less, it will provide a new tool for the study of nonlinear and ultrafast phenomena. Furthermore, once the principles have been demonstrated, the selection of a different linac or linac technology could increase the repetition rate to kiloHertz or higher. One might then reasonably ask why not incorporate these capabilities from the outset? The answer lies in the costs, the budgets, and the obligations of the NSLS. No one reading this annual report will be amazed by the statement that budgets have been extremely tight in recent years, which makes long range planning and investment especially difficult. Nor would the statement that NSLS takes its obligations to its user community very seriously meet with any surprise. The NSLS management and staff continue their commitment to attain the highest possible reliability and availability of the storage rings, while pushing their performance to the greatest extent possible. However, they also recognize their responsibility to explore new source technologies, and have embarked on a program of source development which to the greatest extent possible utilizes existing hardware.

These factors account for the 10 Hz repetition rate limit for the facility, since that was the design point for the 230 MeV linac built as an injector for the SXLS project. So while significant modifications to the linac are required to make it a suitable driver for an amplifier FEL, it provides a huge head start on the SDL accelerator. Similarly, the main undulator for the FEL experiment is recovered from an Army program for a high average power FEL, which is another major element of the facility. The electrical work for control of the 10 meter long NISUS undulator was completed this year in collaboration with STI Optronics, although the required vacuum modifications are being deferred until the completion of the linac installation. An NSLS/ATF designed photocathode gun is being built for the SDL in collaboration with SLAC and UCLA, and a magnetic pulse compressor will be installed to achieve the high brightness-high peak current electron beam required for short wavelength FEL amplifier operation. New diagnostics and controls are also in the process of being implemented on the linac. Building 729 even required some expansion to house the SDL accelerator, which was completed last year. Further modifications to the building, including the chilled water system and the installation of an overhead crane, were completed this year. Early in 1997 the machine water system and a class 1000 cleanroom to house the laser will be installed, completing the "infrastructure" modifications required for the SDL. The focus of activity in the coming year will be the installation and commissioning of the linac. Experiments in non-linear emittance correction and pulse compression are planned, as well as studies to examine various aspects of emittance degradation, which could have a significant impact on the range of FEL operations which are possible. Assembly of the machine to undertake actual FEL experiments will follow as soon as possible. The actual time table for the SDL is very sensitive to the available resources. The same can be said of many other "fourth generation" source projects hence, where reasonably possible, some aspects of the project are being pursued in collaboration with institutions who have programs with technological requirements similar to those of the SDL. In addition, the BNL management continues to support the effort through significant LDRD contributions, although the availability of NSLS staff and other department resources plays a major role in setting the pace of the project. So, while maintaining its high standard for supporting the operation and utilization of the existing storage rings remains the first priority for the department, the NSLS remains committed to moving forward with the SDL, making it very much, a work in progress . .

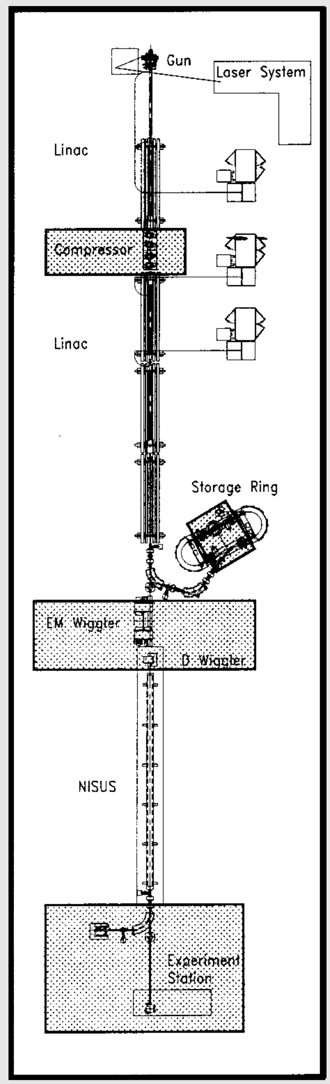


Figure 2: Layout of the SDL accelerator. Components under development are shaded. All others are either under construction or are already in place in building 729.

PROJECTS

THE ACCELERATOR TEST FACILITY

Ilan Ben-Zvi
ATF Head

THE ATF - A USERS' FACILITY WITHIN A USERS' FACILITY

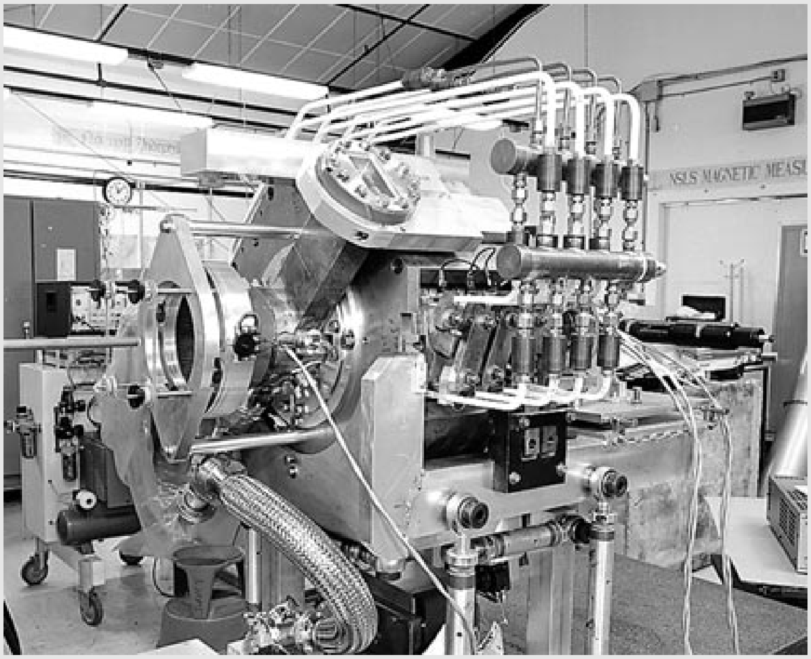
The Accelerator Test Facility (ATF) is a User's Facility for accelerator and beam physicists, operated by the NSLS and the BNL Center for Accelerator Physics. There is no other proposal-driven, peer-reviewed facility like the ATF that is dedicated for long range R&D in accelerator and beam physics. In addition to its singular role the ATF has also a unique combination of a high-brightness electron beam, synchronized, high power lasers and a well equipped, 3 beamline experiment hall. The high brightness electron beam of the ATF, produced by a laser-photocathode RF gun, make it an ideal site for R&D on Free-Electron Lasers (FEL). The ATF receives funding from the DOE and the laboratory directorate as well as important support from the NSLS. The NSLS has an active program in R&D in the production of short-wavelength coherent radiation through its involvement in the ATF. Taking advantage of the expertise and hardware that accumulated at the ATF, the NSLS is pursuing a program that touches the most fundamental issues of short wavelength FEL R&D today, such as the development of electron sources, single pass FEL experiments and more.

TOWARDS A BRIGHTER SOURCE

Electron beams with a high density of electrons in 6-D phase space are the keystone for future high performance machines such as X-ray Free-Electron Lasers and linear colliders, as well as the generation of intense sub-picosecond x-ray pulses through the process of Compton back-scattering of laser pulses off the electron beam. The length of both accelerator and wiggler of any short-wavelength FEL will decrease sharply with improved beam brightness. In a remarkable case of parallel evolution, this work is also important to High Energy Physics for the construction of future linear colliders. Thus the ATF is enjoying considerable support from the DOE Office of High Energy Physics. R&D at the ATF on the generation of high brightness beams placed the NSLS in an international leadership position. The electron gun of the ATF generates its high current, low emittance beam by irradiating a high-quantum-efficiency metal-cathode in the presence of very high intensity RF electric fields. A new magnesium photocathode has demonstrated an order-of-magnitude increase in quantum efficiency with a (so far) unlimited lifetime. The ATF is leading two new collaborations for the development of RF guns, one with SLAC and UCLA, and the other with Japanese collaborators. The ATF's gun is now recognized internationally as "The BNL Gun" and versions of it are in use in many places around the world as well as in BNL's Center for Radiation Chemistry Research and soon at the Source Development Laboratory.

THE USERS OF THE ATF

Among the fourteen currently approved experiments on the ATF, there is a number of experiments dedicated for research into novel radiation generating processes, from the IR to x-rays. Among these are some FEL experiments and an experiment in the generation of Smith-Purcell radiation and Compton back-scattering. A few of them are centered about ATF beamline #3, where a microundulator oscillator experiment is nearing operation and others are conducted on beamline #2, like the High Gain Harmonic Generation FEL, or beamline #1, like the Smith-Purcell experiment and the Compton back-scattering experiment. A superconducting 68 period micro-undulator (with a period of 0.88 cm and 0.5 Tesla peak field at a gap of 0.44 cm) has been developed at the NSLS. Prototypes of this undulator (up to 23 periods long) were built and performed extremely well in superconducting tests. The field errors of the undulator were very low as constructed, making this perhaps the first undulator that will require no trimming after manufacture. The FEL experiment makes use of the short period of the undulator and the low emittance beam generated by the RF photocathode gun to operate at 500 nm with a 50 MeV electron beam. Since the ATF electron beam energy is currently at about 70 MeV, lasing at below 250 nm should be possible. The technology developed for this



The latest ATF RF gun, developed in collaboration with SSRL and UCLA.

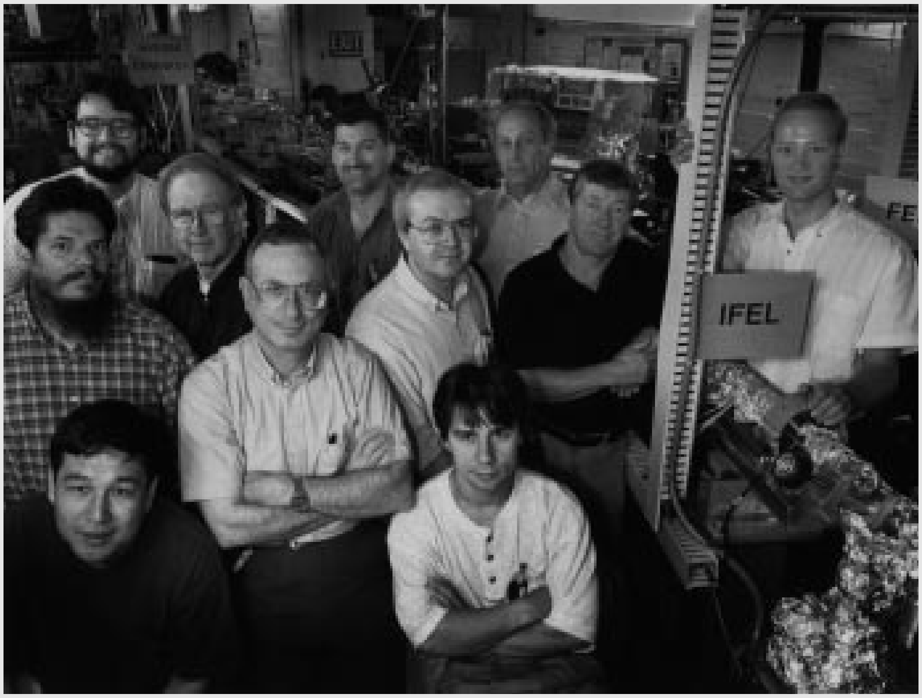
undulator will be used to develop a 4 to 5 mm period, small gap undulator prototype for the National Synchrotron Light Source X-Ray Ring.

An MIT group is carrying out a test of a pulsed microundulator. This undulator, which is currently installed on the beamline, has parameters that are very similar to those of the superferric undulator. Spontaneous emission has already been observed from this device and preparations are under way to get lasing in the near future. A third user group is from Columbia University. They will be using the oscillator experiment for studies of spiking and optical guiding in FELs.

The high-gain harmonic-generation experiment will be located on beamline #2. This experiment is carried out by a NSLS group headed by Li-Hua Yu. In the first stage of this experiment, done in collaboration with the Advanced Photon Source, a two meter long undulator (a prototype of Undulator-A built by Cornell) will be installed to study single pass FEL gain, start-up from spontaneous emission and saturation. The next step of this experiment will be done in collaboration with Northrop - Grumman, which is providing many components of the undulator for the experiment. This undulator is a derivative of the superconducting micro-undulator of the visible FEL oscillator. It uses the same principle of a continuous yoke but has parabolic pole faces for two-axis focusing and four distinct regions: a prebunching undulator, a dispersive section, an exponential growth section and a tapered section. This experiment emulates the FEL physics of the NSLS approach to VUV FELs. This approach is based on single pass, seeded FEL amplifiers driven by Ti:sapphire lasers. The final stage of harmonic generation is being done in the FEL. The principle of high-gain harmonic-generation will be tested and characterized in these experiments, as well as the superconducting undulator, the undulator diagnostics, error and alignment studies and tapering control. Another experiment at beamline #2 has recently broken the world record for Inverse FEL acceleration of electrons. This experiment, headed by Arie van Steenbergen, used the high-power CO_2 laser of the ATF and a special variable period wiggler to impart 2% acceleration to a 40 MeV beam, using about 0.5 GW of the CO_2 laser. This experiment, which is like an FEL amplifier operated in reverse, is motivated by the interest to develop a compact, high-gradient electron accelerator.

ACCELERATOR R&D AND GRADUATE EDUCATION AT THE ATF

Two significant experiments have been recently reported by the ATF staff. The first is a measurement of the slice-emittance of an electron bunch from the ATF electron gun. This newly developed technique makes it possible to study in detail the longitudinal dependence of the transverse beam-matrix of short slices with 1 picosecond resolution. The slice-emittance measurement enabled us to examine the evolution of the beam while it goes through the important emittance-compensation process. Emittance compensation is a linear correlation-removal process that has led to the improvements in photocathode RF gun beam brightness and to the recent enhanced interest in x-ray FELs. The slice-emittance measurement should allow us to do non-linear emittance corrections that promise even better x-ray FELs. The second development is the observation of micro-bunching of the ATF'S beam. Under certain conditions it is possible to obtain



NSLS Staff Assigned to the Accelerator Test Facility (ATF):
(Top, from left to right) John Skarita (Mechanical Section), Marc Montemagno (Electronics), and Igor Pogorelsky (Lasers).
(Middle, from left to right) Bob Harrington (Mechanical and Optical Systems), Joe Sheehan (Electrical Section), Robert Malone (Computer and Control),
Bill Cahill (Technical Supervisor and Users' Coordinator),
and Marcus Babzien (Lasers).
(Bottom, left to right) Xijie Wang (Accelerator, gun, diagnostics), Ilan Ben-Zvi (Head of ATF) , and Vitaly Yakimenko (Accelerator, gun, diagnostics).

sub-picosecond long bunches with a high charge and good emittance. This happens when the photocathode laser is adjusted to a small phase, leading to bunch compression in the drift space between the gun and the linac. One picosecond bunch length have been measured (using a variation of the slice emittance set-up). Much shorter bunches are predicted theoretically, but await a further refinement of Eric Blum's coherent radiation detector. Eric has already observed coherent radiation from the ATF's beam. An installation of a spectrometer will allow sub-picosecond bunch length measurement. The motivation for this R&D is that sub-picosecond bunch length, high brightness electron beams can generate high-intensity, sub-picosecond radiation from the far-IR to x-rays.

As a result of the bunch compression, the bunch length of the ATF can be changed easily from about 10 picoseconds to under one. If this bunch is collided with an energetic pulse from the ATF'S synchronized CO_2 laser, a pulse with the same short length of x-rays is produced. Compton back-scattering of lasers by electrons is a unique x-ray source. Preliminary estimates indicate that it should be possible to generate elliptically polarized $2x10^8$ photon pulses of 8 keV x-rays using the ATF'S future 1 TW CO_2 laser and its 70 MeV linac. A contract for the construction of parts for the ATF'S compact picosecond Terawatt laser has been signed last year.

In a significant contribution to the education of future generation of accelerator physicists, eight graduate students have finished their thesis at the ATF and six others (from Columbia, MIT, Stanford, Stony Brook UCLA and the University of New Mexico) are currently doing thesis research at this facility. More information on the ATF can be found on the World Wide Web, with a hyperlink from either the National Synchrotron Light Source or BNL Home Pages.

NSLS Facility Improvements

Frank Terrano
Mike Kelly

Although there was no major construction at the NSLS during FY 1996, a number of facility related projects were accomplished and initiated.

BUILDING #725 RAMP TO INNER X-RAY RING AREA

The driveway which provides access to the inner courtyard of the x-ray ring was resurfaced and regraded. This was done to prevent puddles from occurring and eroding the concrete over the X-Ray Ring and x-ray power supply areas.

BUILDING #725 TURNAROUND

The circular drive at the main entranceway to building #725 was becoming unsightly due to cracks and puddles resulting from uneven grading. When combined with freezing temperatures, the puddles presented a safety hazard as well. The area was resurfaced and graded thus eliminating the puddles and improving the overall appearance.

COOLING TOWER REPLACEMENT

A jointly funded NSLS/BNL Plant Engineering Division project has been implemented for the replacement of the sixteen year old Baltimore Cooling Tower on the roof of building #725. This is one of two cooling towers which are part of the NSLS "in house" chilled water system. This system provides coverage during shutdowns of BNL's central chilled water facility which is becoming our primary source of machine and comfort cooling. The tower was purchased during late summer/early fall, with installation completed in December 1996.

EXPERIMENTAL WATER UPGRADE

The connection of the experimental water system is the final phase of the NSLS hookup to BNL's central chilled water facility. This project gives the NSLS the added reliability and operating flexibility of being able to cool the experimental water system from both the central chilled water system and the NSLS "in house" chilled water system. Installation will be completed during the December 1996 shutdown.

BUILDING #729 TWO TON BRIDGE CRANE

This Project installed an overhead crane to cover approximately ninety percent of the floor area in building #729, which houses the Source Development Laboratory.

IMPROVEMENTS TO THE EXPERIMENTAL FLOOR AREAS

Recognizing the concerns expressed in the responses to a DOE survey of NSLS users taken in the Spring of 1996, we have taken steps to remedy three commonly repeated themes; seating, sound levels and lighting.

During the summer months, over two hundred new multi-adjustable swivel arm chairs were purchased and distributed throughout the X-Ray and VUV experimental floor areas. These chairs have replaced the worn out "old gray chairs", adding much to the comfort and appearance of the facility.

Sound surveys had been performed around the X-Ray and VUV Ring areas in 1994 both before and after sound insulating panels were installed in the VUV area. Recently in the summer of 1996 sound surveys were again conducted and experts are being consulted in a continuing effort to minimize noise levels. Results of these surveys can be found on a poster in the main lobby of building #725. Comments or suggestions are invited.

A 400 Watt mercury vapor lamp fixture was installed over the main entrance area to the VUV Ring on a trial basis. This fixture has replaced the original 250 Watt high pressure sodium lamp which is the type currently used throughout the experimental areas. The mercury vapor lamp is brighter and sheds a whiter "daylight" type of lighting than the yellow and dimmer sodium lamp. The feedback from the users in the area has been generally favorable and we are currently in the process of obtaining estimates for the replacement of all the lighting fixtures on the X-Ray and VUV experimental floor.

Insertion Device R&D at X13

Peter M. Stefan
Sam Krinsky
Chi-Chang Kao

On the NSLS X-Ray Storage Ring, the X13 straight section and beamline have been used for insertion-device-related R&D since 1990. The development work at X13 has succeeded in significantly advancing the state-of-the-art in important aspects of insertion device design, and the light sources produced have the promise of delivering significant new capabilities for the NSLS user community. Three important projects will be described below: the Prototype Small-Gap Undulator (PSGU), the in-vacuum undulator (IVUN), and the Time Varying Elliptically Polarized Wiggler (EPW). The PSGU and the EPW are presently installed for use at X13. IVUN is under construction, and in Spring of 1997 it will be installed at X13, replacing the PSGU.

SMALL-GAP UNDULATORS

The PSGU [1,2] combines a short-period (16 mm) undulator magnet and a variable-aperture vacuum chamber to produce high-brightness undulator light with a higher photon energy in the fundamental than would otherwise be possible in the X-Ray Ring. The PSGU was built in a collaboration between the NSLS and Rockwell International Rocketdyne Division. Rocketdyne built the permanent magnet arrays. The light produced by the PSGU is concentrated in the fundamental and in a few higher harmonics, as illustrated in Figure 1 for a magnet gap of 7.5 mm. The brightness is between 100 and 1000 times that of the X-Ray Ring bend magnet sources, while the flux in the fundamental is about equal to that from 8 milliradians of the bend magnet.

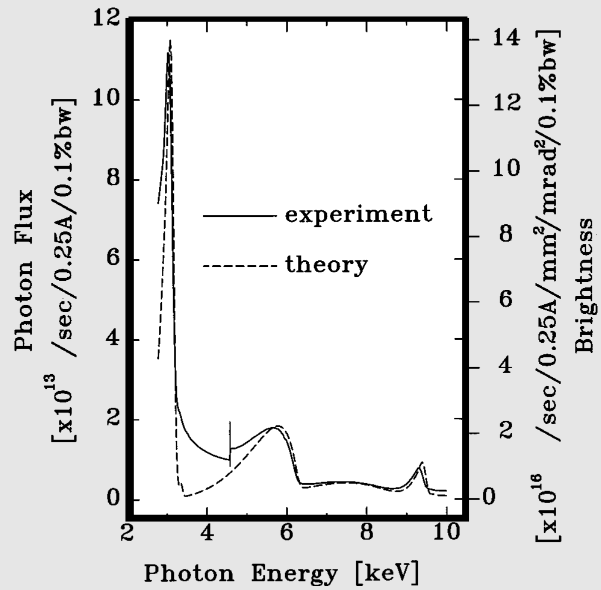


Figure 1: Spectrum measured from the PSGU undulator, for a magnet gap of 7.5 mm, K=0.716, at 2.584 GeV, 26 mA, with an electron beam full aperture of 3.8 mm. The theory curve was obtained using the URGENT code [9].

Photons from the PSGU have been used to develop a coherent x-ray beam for X-ray Photon Correlation Spectroscopy (XPCS). A coherent beam of $3x10^9$ photons/sec at 3 keV (4.1Å) was produced through a 10 μm pinhole.

The long straight sections of the NSLS X-Ray Ring (such as the X13 straight) are particularly well-suited for small-gap insertion devices. The stored electron beam focuses to a minimum dimension both in the vertical and in the horizontal at the center of the long straight. The same strong focussing occurs for an imaginary tube surrounding the electron beam, which represents a "stay-clear" aperture. As long as the vacuum chamber stays outside the stay-clear region, the beam lifetime is unaffected. Therefore, the PSGU is installed in the center of the straight section, and is quite short. The minimum-aperture-region of its variable vacuum chamber is 390 mm long, and the undulator magnet arrays are 320 mm long. In the regions closest to the electron beam, the PSGU vacuum chamber is thinned to 1 mm. The magnet arrays are in air, located just outside the thinned vacuum chamber. The magnet gap is always at least 3 mm greater than the vertical aperture of the vacuum chamber for the electron beam.

One of the most important studies conducted with the PSGU determined the vertical dimension of the stay-clear tube mentioned above, and measured the reduction in the electron beam lifetime as the variable vacuum chamber cut into this tube. The results are illustrated in Figure 2. The lifetime was essentially unaffected to a full aperture of 4 mm, but then started to decrease. In a practical sense, an aperture of about 3 mm is operationally acceptable, since the overall lifetime reduction is small.

In order to take full advantage of the ability to run with a 3 mm aperture, we are pursuing an in-vacuum undulator project (IVUN). This is a logical extension of the PSGU, with the variable vacuum chamber eliminated, and the undulator magnet arrays placed directly in the storage ring vacuum. For IVUN, the magnet gap and the corresponding electron beam aperture are very nearly the same dimension. A comparison between the parameters of the PSGU and IVUN is presented in Table 1.

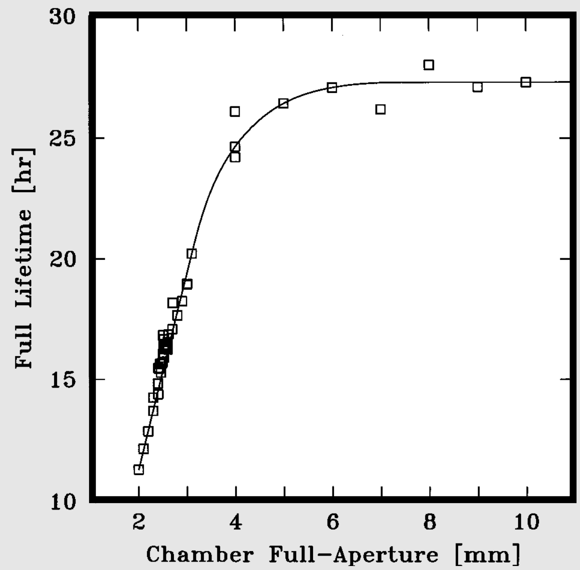


Figure 2: Stored beam lifetime as a function of the electron beam aperture presented by the PSGU vacuum chamber, at 220 mA. The line drawn is a guide for the eye.

Table 1: PSGU/IVUN Comparison

	PSGU	IVUN
Period λ_u	16mm	11 mm
Nominal Magnet Gap	6.0 mm	3.3 mm
Corresponding Maximum Beam Aperture	3.0 mm	3.0 mm
Peak On-Axis Field	0.623 T	0.678 T
$h\upsilon_{1\ out}$, ($\lambda_{1\ out}$)	2.77 keV, (4.48 Å)	4.64 keV, (2.67 Å)

The IVUN design goal is for a photon output at 4.6 keV (2.7Å) in the fundamental, with high flux at the second and third harmonics, at a magnet gap of 3.3 mm. Experiments spanning the whole spectrum of synchrotron-light applications, from spectroscopy and diffraction to microscopy and scattering, can benefit from this high-brightness, high-flux source. In addition the electron beam characteristics of the X-Ray Ring allow IVUN to produce good second-harmonic intensity on-axis, at just over 8 keV, with a half-intensity bandwidth of over 2 keV. IVUN is being built in a collaboration between the NSLS and the Japanese SPring-8 Project. Our collaborators at SPring-8 worked on the first successful in-vacuum undulator and are fabricating the 11 mm-period magnet arrays for IVUN. When installed in the X13 straight section, IVUN will replace the PSGU,which is now situated at the center of the straight. Studies are planned to begin in the Summer of 1997.

TIME VARYING ELLIPTICALLY POLARIZED WIGGLER

The Time Varying Elliptically Polarized Wiggler (EPW) [3] is a very different kind of insertion device, compared with the PSGU or IVUN. As the name implies, it produces elliptically-polarized light on axis, with the sense of rotation of the field vectors, i.e. the helicity, alternating at up to 100 Hz. The EPW was built in a collaboration between the NSLS, the APS at Argonne National Lab, and the Budker Institute of Nuclear Physics at Novosibirsk. Usable fluxes of photons are available from 100 eV to 10 keV, with the measured degree of circular polarization exceeding 50%. Such a source is extremely useful for circular dichroism studies of both magnetic materials and materials with natural optical activity. The stable alternation of the helicity, at frequencies up to 100 Hz, is an extremely powerful aspect of the source. This allows gating or lock-in techniques to separate the responses of the sample to opposite helicities. When a lock-in amplifier is used, any steady-state or background signals are summarily removed from the start, since the lock-in only detects the signals which follow the EPW reference signal. Adjustment of the lock-in phase selects the sample response to the individual helicities. This holds the promise of being a very sensitive probe for circular dichroism.

The concepts [4] behind the EPW are also quite interesting, and may be explained as follows: First consider the synchrotron light emitted by a bend magnet source in a storage ring. In the NSLS X-Ray Ring, as viewed from above, the electron beam enters a bend magnet and makes a gentle turn to the right. The light emitted into the horizontal plane (which contains the electron beam path) is linearly polarized, with the electric field vector contained in this same plane. Light directed above or below the plane is elliptically polarized, with opposite helicity above and below. In a normal wiggler, the electron beam makes a bend to the right, then one to the left, etc. The polarization of the output light from the wiggler is linear everywhere, that is, in the plane of the wiggles and above and below. This is due to a cancellation of the elliptical nature of the *right* turns by the *left* turns. In the EPW, a special electromagnet adds vertical deflection to the electron trajectory, as illustrated in Figure 3. The right and left turns are twisted out of the horizontal plane, but with all the right turns twisted *up* and the left turns twisted *down*. The photons illustrated in the figure were initially directed parallel to the z direction, before the twists were applied. As a result, the light which is now directed parallel to the z direction comes from *below* the plane of the right turns and *above* the plane from the left turns. Thus, it is elliptically polarized, with the two types of turns re-enforcing each other. When the current flow in the electromagnet is reversed, the opposite helicity is produced on axis.

The EPW was installed in December 1994, commissioned during Spring 1995 at an operating frequency of 2 Hz, and became operational subsequently [5]. Utilizing trim coils at the wiggler ends and the high-precision

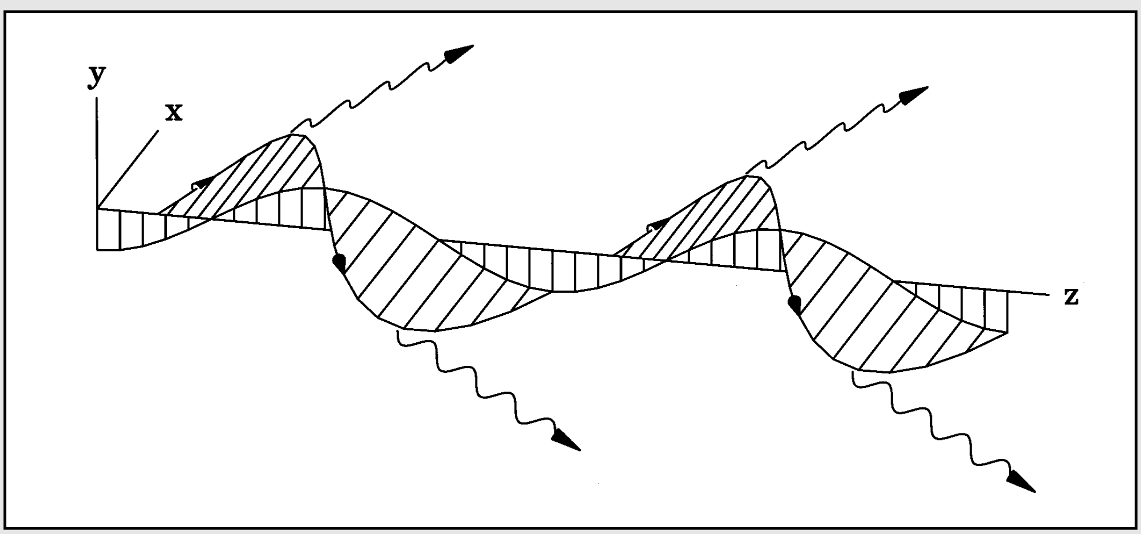


Figure 3: The electron trajectory in the EPW. A special electromagnet adds the vertical deflection to the electron trajectory. The right and left turns are twisted out of the horizontal plane; all the right turns are twisted *up* and the left turns twisted *down*. The photons illustrated in the figure were initially directed parallel to the z direction, before the twists were applied.

orbit measurement system of the NSLS X-Ray Ring, the residual orbit motion was reduced to a level below 0.5 μm [6]. No adverse effects on other experiments have been observed. The degree of circular polarization of the radiation from the wiggler was characterized by making Magnetic Circular Dichroism (MCD) measurements using the X13A soft-x-ray beamline [7]. For vertical deflection parameters, K_x, of 1.2 and 1.6, the MCD effects at the Fe $L_{2,3}$ edges indicated a degree of circular polarization of 60% and 75%, respectively, in good agreement with calculated values. Experimental programs based on the device, including MCD, Natural Circular Dichroism, and Resonant Magnetic Scattering, have also started. As an example, very small MCD effects near the Cr $L_{2,3}$ edges were observed in a series of Co-Cr alloys (a promising candidate for a high-density perpendicular magnetic recording medium) by a collaboration of the Naval Research Laboratory, AT&T, and the NSLS [8]. From these results, the Cr in the alloys was found to be polarized, and the induced Cr moment aligned anti-ferromagnetically with respect to that of the neighboring Co. These results also showed that MCD effects much smaller than 1% can be easily detected with the EPW, as illustrated in Figure 4. To fully utilize the EPW, a new soft x-ray spherical grating beamline and a double-crystal x-ray monochromator are being constructed, and will be operational in fiscal year 1997. Studies are now underway utilizing the EPW switching at 100 Hz.

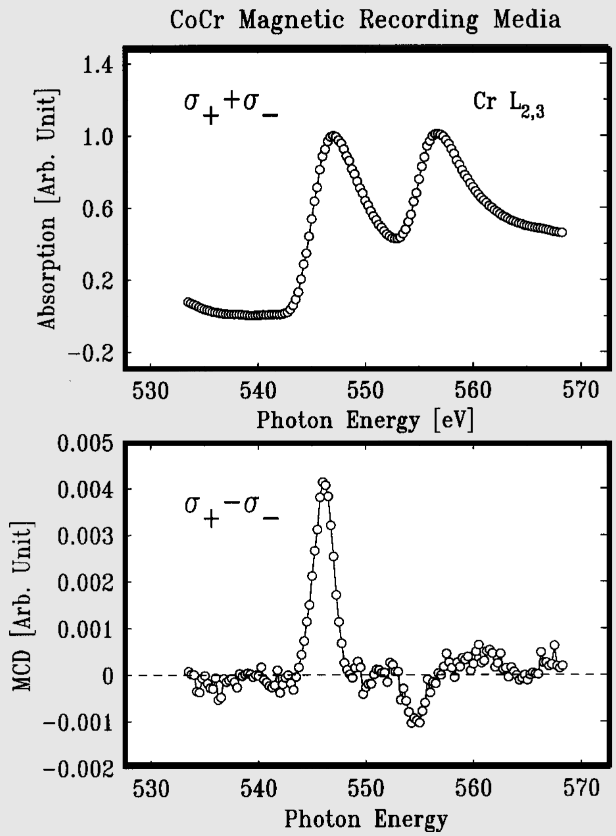


Figure 4: Magnetic Circular Dichroism (MCD) effects near the Cr $L_{2,3}$ edges in a series of Co-Cr alloys [8]. From these results, the Cr in the alloys was found to be polarized, and the induced Cr moment aligned anti-ferromagnetically with respect to that of the neighboring Co. The MCD effect illustrated is much smaller than 1%.

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